

The Rate of Body Heat Storage in Subjects Wearing a Prototype Firefighter Ensemble

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Introduction

- Firefighter (FF) ensembles impose significant heat stress on the wearer (both metabolic and environmental). This heat stress can negatively impact physical performance and health.
- In addition to their normal duties, FF may be called to incidents involving chemical and biological (CB) hazards. To address this concern, a FF prototype ensemble (PE) with CB protection was developed.
- The PE contains several design features (Fig 1) which may impact the wearers physiological responses. For example, the PE rerouted Self-Contained Breathing Apparatus (SCBA) exhaust air back into the torso to provide convective heat loss.

Purpose

- To examine the physiological responses to wearing the PE either with the hose attached (PEWH) or not attached (PENH) compared to a standard FF ensemble (SE).
- To compare the rate of body heat storage (S, measured in kJ/min) in response to wearing PE with SCBA (PE + SCBA; total weight - 21.21 ± 0.37 kg) exhaust gas re-routed into the ensemble to SE (SE + SCBA; total weight - 19.96 ± 0.38 kg) during exercise.



Figure 1. PE new design features: booties, gloves, integrated hood, and hose.

Methods

- Ten healthy subjects (7 men and 3 women) participated in this study (Table 1). Subjects performed treadmill exercise at 50% $\text{VO}_{2\text{max}}$ in an environmental chamber (22°C, 50% RH) (Fig. 2) while wearing the PE or SE. Heart rate (HR, beats·min⁻¹), mean skin temp (T_{sk}), core body temp (T_{c}) were recorded before and during treadmill exercise. Mean body temperature (T_{b}) was calculated as: $T_{\text{b}} = 0.8T_{\text{c}} + 0.2T_{\text{sk}}$, and performance time (PT) was the total exercise time for each individual. Total body heat storage (THS) and S were calculated using thermometric methods. Table 2 summarizes the measurement variables and abbreviations.
- Subjects were randomly assigned to either the PEWH, the PENH or the SE. Subjects breathed through their SCBA respirator connected to a large air volume so as to not limit PT.
- Total exercise time (used to determine PT) was set to a maximum of 45 minutes or when the test was stopped either by the subject (voluntarily) or the investigator upon the subject reaching one of the predetermined test termination criteria (e.g., 90% max heart rate).

Table 1: Subjects characteristics							
Subjects	Age (yrs)	Height (m)	Weight (kg)	BMI (kg/m ²)	Body fat ^a (%)	A _D ^b (m ²)	VO _{2peak} ^c (ml·kg ⁻¹ ·min ⁻¹)
10	25.3 (5.9)	1.7 (0.1)	73.1 (13.5)	23.8 (2.6)	13.4 (4.7)	1.9 (0.2)	45.2 (7.5)

Values are mean (standard deviation, SD); a: percent body fat calculated using 3 skinfold (chest, abdomen, thigh) measurements; b: Dubois body surface area; c: the highest VO₂ obtained during a maximal graded exercise testing using Modified Bruce Protocol.

Table 2: Measurements variables and abbreviations	
Variables	Abbreviation
Standard ensemble	SE
Prototype ensemble with the hose	PEWH
Prototype ensemble without the hose	PENH
Heart rate (beats·min ⁻¹)	HR
Core body temperature (°C)	T _c
Mean skin temperature (°C)	T _{sk}
Mean body temperature (°C)	T _b
Performance time (min)	PT
Total body heat storage (kJ)	THS
The rate of body heat storage (kJ/min)	S



Figure 2. Subject during experimental session wearing PEWH.

Results

- Subject PT while wearing SE was longer compared to the PEWH (p=0.005) and PENH (p=0.001) (Fig 3A).
- Although subjects wearing SE performed significantly longer than while wearing PEWH and PENH, there were no significant differences in absolute T_c and T_{sk} elevation at the end of experimental session between experimental conditions.

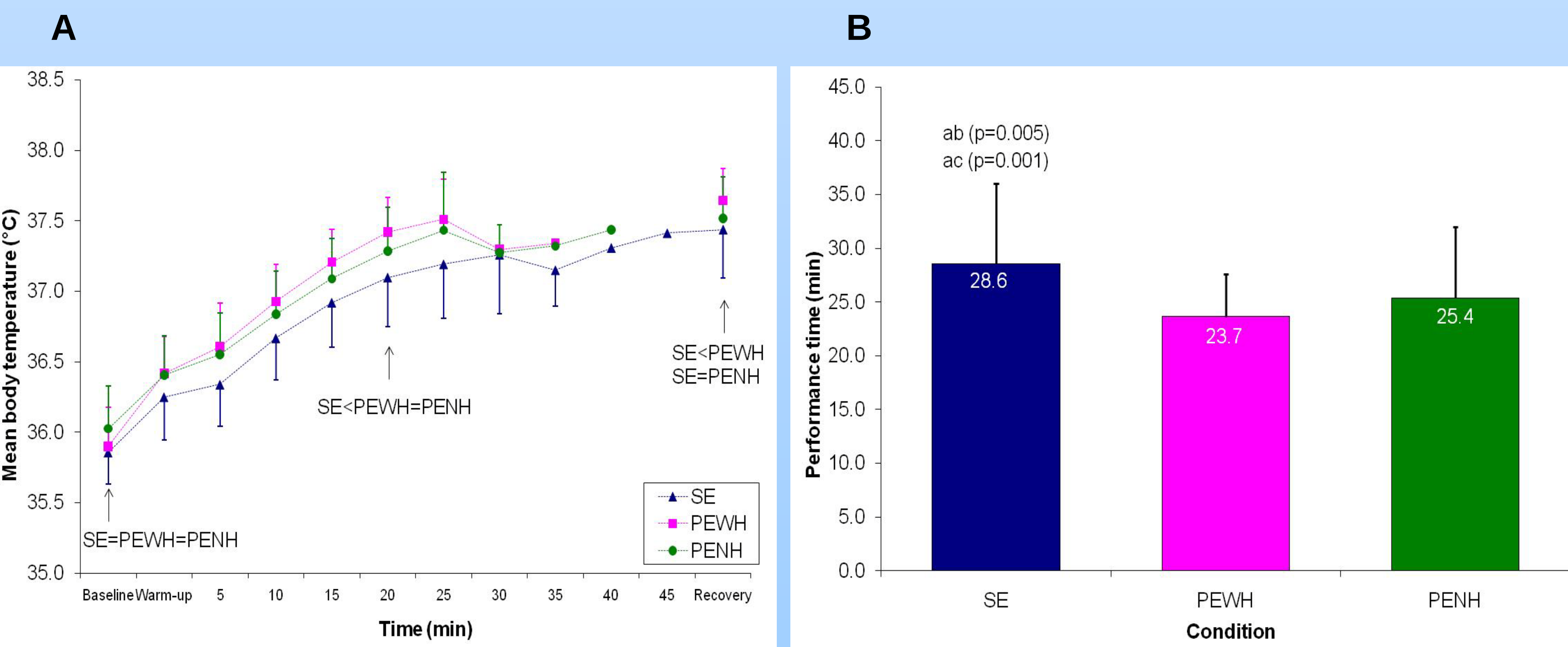


Figure 3. Performance time (PT) (A) and dynamics of mean body temperature (B). PT (min) refers to total treadmill exercise duration completed after 2 min warm-up until any exercise termination criteria was reached. PT varied with each subject in the following manner: Baseline – 20min (n=10), 25min (n=8-7-6; SE-PEWH-PENH, respectively), 30min (n=8-1-4), 35min (n=6-1-4), 40min (n=1-0-1), 45min (n=1-0-0), Recovery (n=10). Values are mean ± SD.

- Progressive increase in T_b was observed in all subjects over the duration of the exercise, the level of T_b after 20 min of exercise was lower in the SE (p<0.05) compared to PEWH and PENH (Fig 3B).
- After 5 min recovery following treadmill exercise, there was no significant difference in HR recovery between the different experimental conditions.
- THS was lower in PENH compared to PEWH (p=0.029) but was not different from SE (Fig. 4A).
- S in PEWH was greater than in SE (p=0.044) and PENH (p=0.05). But there was no difference between SE and PENH (Fig. 4B)

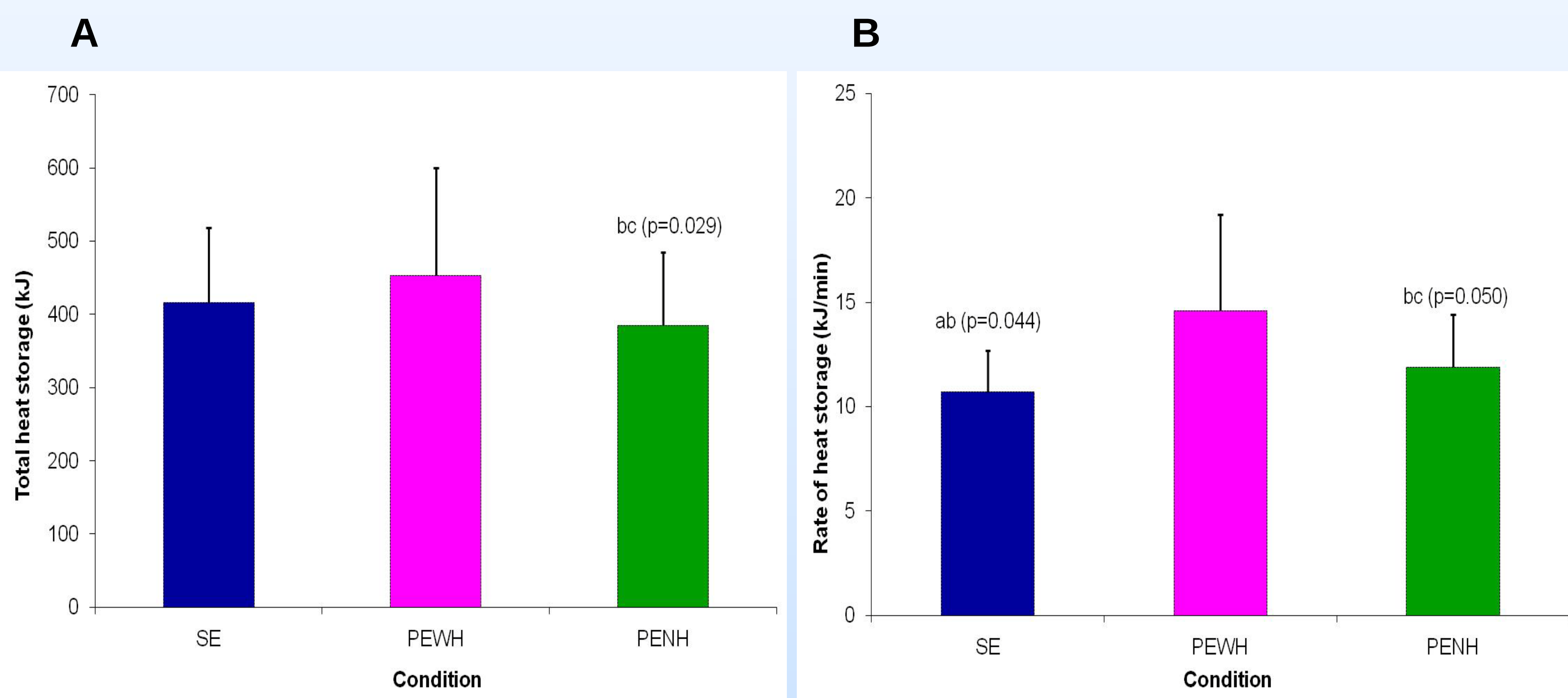


Figure 4. A: Total body heat storage (kJ) represents changes in body heat storage from baseline to the end of 5 min recovery. B: Rate of body heat storage (kJ/min) represents total body heat storage divided by the total exposure duration from baseline to recovery.

Conclusions

- Subjects wearing the SE exhibited significantly greater PT compared to wearing either the PEWH or the PENH.
- S was greater in PEWH compared to PENH and SE.
- This result is counterintuitive since the hose arrangement attempted to provide some convective cooling. However, the exhaust gases from the hose are warm and humid which may result in a limited potential for evaporative heat exchange due to an increase in microclimate temperature and humidity.
- THS in SE was not significantly different from PEWH or PENH due to the fact that the subjects wearing SE exercised for a longer duration.
- The results of the study suggest that, in spite of the air flow from the exhaust gases of the SCBA being re-routed to the ensemble, PE imposes a greater level of thermal strain on a wearer than SE as evidenced by a greater S in PE compared to SE. This is also supported by the increase in HR, T_{sk}, T_b, and decreased PT in subjects wearing PE compared to SE. Thus, the airflow from the exhaust air attached to the PE did not reduce the physiological “burden” of the PE compared to the SE.

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